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AN EXPERIMENTAL STUDY OF THE EFFECT OF OPERATOR HANDS ON THE REACTIVITY OF A FAST METAL SYSTEM

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ABSTRACT

A standard practise in Nuclear Criticality Safety (NCS) evaluations is to use 2.54 cm (one inch) of close-fitting water reflection around fissionable materials to bound the reflection provided by operators' hands. This practise anecdotally seems to arise from NCS pioneering handbook recommendations and engineering judgment more than experimental evidence. Since 2006, Lawrence Livermore National Laboratory (LLNL) has been measuring the effect of human hands on the reactivity of a highly enriched uranium (HEU) metal training assembly as part of hands-on training for NCS engineers. This paper details the results of these measurements and demonstrates that the 2.54 cm criterion is highly conservative in bounding reflection from operator hands. Thus, relaxation of the 2.54 cm criterion to account for reflection by operator hands may be warranted in some cases.

Key Words: operator hand reflection, subcritical experiments

1 INTRODUCTION

Fissile material operations with unirradiated materials largely require the need for personnel to engage in "hands-on" activities. Human hands have a number of characteristics of high-worth neutron reflectors, including being comprised of moderating material (water) and having the ability to conform to the outer contours of items. Since it can be close-fitting, reflection by operator hands is generally the largest contributor to "nominal" reflection, or reflection due to the local operational environment from other nearby equipment and structures. To account for "nominal" reflection, a standard practise in Nuclear Criticality Safety (NCS) evaluations is to use 2.54 cm (one inch) of close-fitting water reflection around fissionable materials. This practise anecdotally seems to arise from NCS pioneering handbook recommendations and engineering judgment more than experimental evidence. Since 2006, Lawrence Livermore National Laboratory (LLNL) has been measuring the effect of human hands on the reactivity of a highly enriched uranium (HEU) metal training assembly as part of hands-on training for NCS engineers [1]. The data collected from these measurements provides an experimental basis for the worth of operator hands.

1.1 Training Assembly for Criticality Safety

The Training Assembly for Criticality Safety (TACS) is a subcritical assembly composed of eight nesting hemi-shells of 93% enriched uranium (Figure 1) that fit together to form a 23 kg sphere with a central cavity. The outer radius of the HEU is 7.925 cm. Lucite (acrylic, $C_5O_2H_8$) moderators of varying thicknesses can be placed inside the cavity and hemispherical Lucite reflectors of varying thicknesses can be fit on the outside of the assembly. The TACS is assembled on an assembly table that can be raised and lowered by means of a hand crank (Figure 2).

Figure 1: Eight HEU shells (left) and four nested shells that form lower half of the assembly (right).

In its most reactive configuration with 10 cm Lucite radial reflection and 700 grams of Lucite moderation, the TACS subcritical assembly achieves a maximum multiplication of approximately 10, corresponding to an effective multiplication factor (k_{eff}) of approximately 0.90. The assembly is driven by a neutron source to quickly obtain meaningful count rate data with a neutron detector.

The neutron detector consists of four 2 atm ^3He tubes embedded in a block of polyethylene. The tubes have a 5 cm diameter and an active length of 38 cm. The ^3He tubes are connected to an Eberline E-600 portable radiation monitor that displays the neutron count rate data.

Figure 2. The Training Assembly for Criticality Safety, shown with a 3"gap separating the hemispherical halves.

1.2 Experimental Method

In addition to the HEU shells, there is a set of nearly identical surrogate depleted uranium (DU) shells. The combination of DU and HEU shells allowed for experimental determination of multiplication, which was found using the following method. A non-multiplying assembly was constructed using depleted uranium (DU) shells, the neutron source, and the desired level of moderation and reflection. A neutron count rate measurement was taken, which determined the baseline of unmultiplied source neutrons emitted from the assembly. This count rate was assigned as C_0. The DU shells were then removed and replaced with the similar HEU shells with the same source, moderator, and reflector configuration. Another count rate was taken (C). By dividing this second multiplied count rate by the baseline unmultiplied source count rate, corrected for background neutron counts (C_b), an experimentally observed multiplication, M_{obs}, was determined (Equation 1).

$$M_{obs} = \frac{C - C_b}{C_0 - C_b} \tag{1}$$

2 METHOD

Equating reflector worth of operator hands to a radial thickness of water reflection required a number of steps. M_{obs} was experimentally measured for the assembly reflected by different hand configurations. Using a multiplication curve experimentally derived from the TACS with varying thicknesses of Lucite (acrylic) reflection, an equivalent Lucite reflection thickness was determined for each hand configuration. A Monte Carlo calculation was employed to convert the Lucite reflection thickness to an equivalent water reflection thickness. Additional details are given in the following sections.

2.1 Measurement of Operator Hands

During each experiment, one operator with small hands and one operator with large hands were selected. The surface areas of their hands were determined by tracing onto graph paper and their hand volumes were found by displacing water in a graduated cylinder. Multiplication of the assembly was measured for six different hand configurations: one small hand, two small hands, one large hand, two large hands, three hands, and four hands. The picture sequence in Figure 3 shows the operator hand and body placement relative to the TACS. Operators wore thin nitrile gloves for contamination control and placed their hands directly on the outer nickel-plated HEU hemi-shell. For consistency, the three hands measurement was always taken with hands on the top of the assembly, as shown in 3.v. The fourth hand was always placed on the bottom half of the assembly, where the lower, movable platform on which the HEU rested made surface area coverage difficult, shown in 3.vi.

i.) One Small Hand ii.) Two Small Hands iii.) One Large Hand

iv.) Two Large Hands v.) Three Hands vi.) Four Hands

Figure 3 (i-vi). This series of photographs show operator hand and body placement relative to the TACS for all six hand configurations. Hands were placed directly on the nickel-plated HEU shells for maximum effect. The polyethylene block of the neutron detector can be seen in the background.

2.2 Conversion of Hand Reflector Worth to Lucite Reflector Thickness

Sets of Lucite reflector shells, ranging in thickness from 0.5 cm to 10 cm, were used around the outside of the TACS in the laboratory to construct an "Approach to Critical" curve (shown in Figure 4). By plotting inverse multiplication ($1/M_{obs}$) versus the Lucite reflector thickness and linearly extrapolating to the point when $1/M_{obs}$ reaches zero, an estimate of the reflector thickness needed to achieve criticality can be made. Since the TACS assembly is subcritical, the curve does not actually cross the x asis. For each M_{obs} obtained for an operator hand configuration, this Lucite Approach to Critical curve was used to determine a corresponding Lucite reflection thickness. For example, if one large hand resulted in an experimental M_{obs} of 2 ($1/M_{obs}$ of 0.5), using the curve in Figure 4, this would correspond to a Lucite reflector thickness of approximately 0.5 cm.

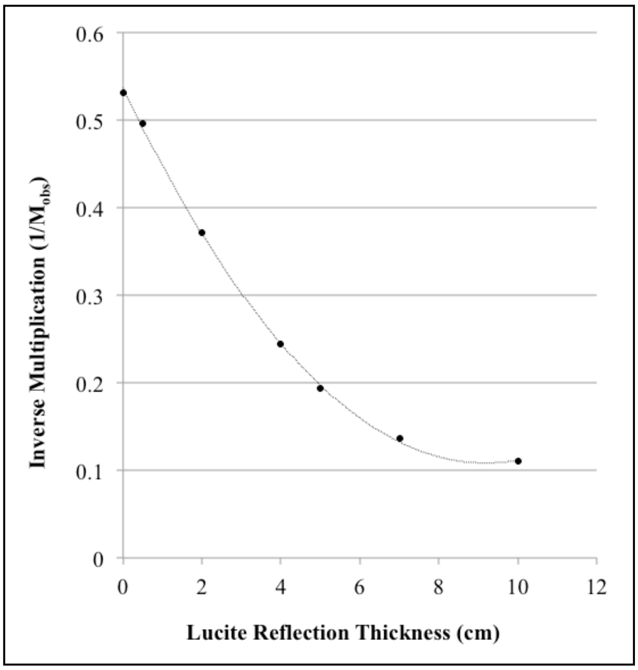

Figure 4: Approach to Critical by Lucite Reflection Curve

2.3 Water Thickness Equivalence

The final step in determining a water reflection thickness equivalence for the experimentally measured operators hands employed a computational method. The TACS hemi-shells, including 700 grams of internal Lucite moderator and the 7.54 diameter aluminium source holder, were modelled using the multiparticle Monte Carlo radiation transport code COG, Version 10 (COG10) [2]. Two sets of criticality calculations were completed, one with varying thicknesses of external Lucite reflection and the other with varying thicknesses of water reflection. A 2-D representation of the 3-D spherical geometry for the COG10 calculations is shown in Figure 5.

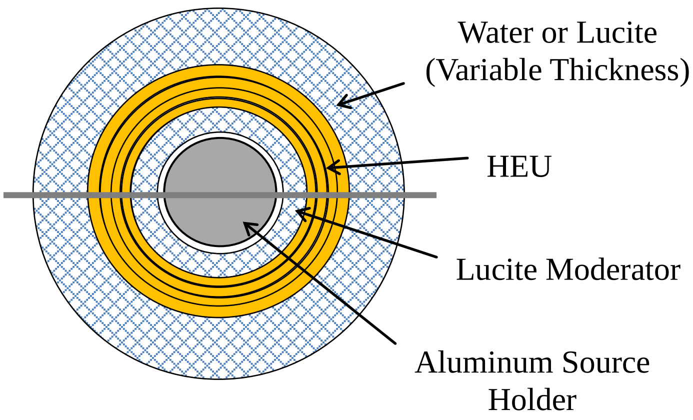

Figure 5: COG10 geometry for calculations investigating the reactivity effect on the TACS of varying thicknesses of water and Lucite external reflection.

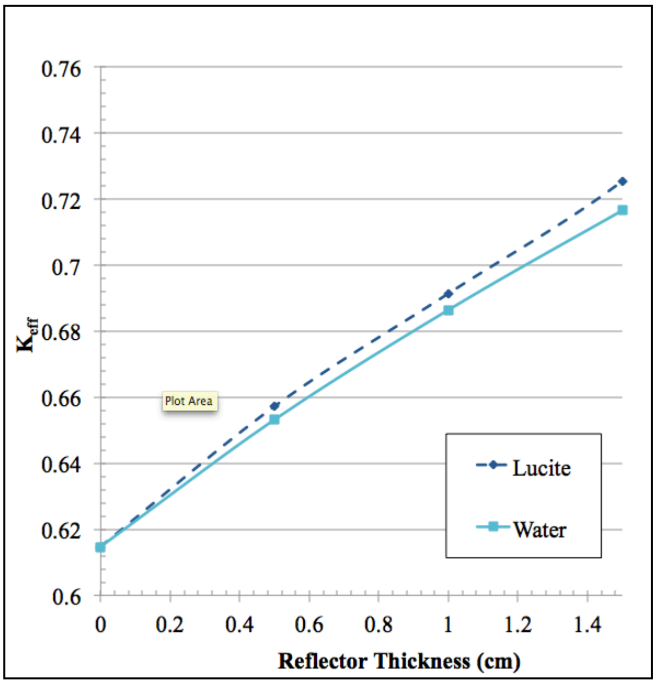

Figure 6: COG10 Results comparing Lucite and Water reflection thicknesses and their effect on reactivity.

The results of the COG10 calculations for Lucite and water reflection are plotted against each other in Figure 6. The uncertainties in the COG10 calculations were kept below 0.001. Lucite is a more effective reflector than water, as illustrated by the fact that Lucite results in a higher effective multiplication factor for the same reflector thickness as water.

As described in Section 2.2, each operator hand measurement was converted into an equivalent Lucite reflection thickness. Using Figure 6 and the Lucite reflection thickness, an equivalent water reflection thickness was found that resulted in the same COG10 effective multiplication factor. Thus, an equivalent water reflection thickness was established for each experimental operator hand configuration.

3 RESULTS

A total of 52 person's hands (26 small and 26 large) were measured during this study, resulting in 126 individual multiplication measurements. Hands ranged in surface area from 100-200 cm^2, corresponding to hand volumes from 275-600 cm^3.

The equivalent water reflection thicknesses for all measurements are shown in the following graphs as a function of hand surface area (Figure 7) and hand volume (Figure 8). A trendline is provided as a guide to the eye.

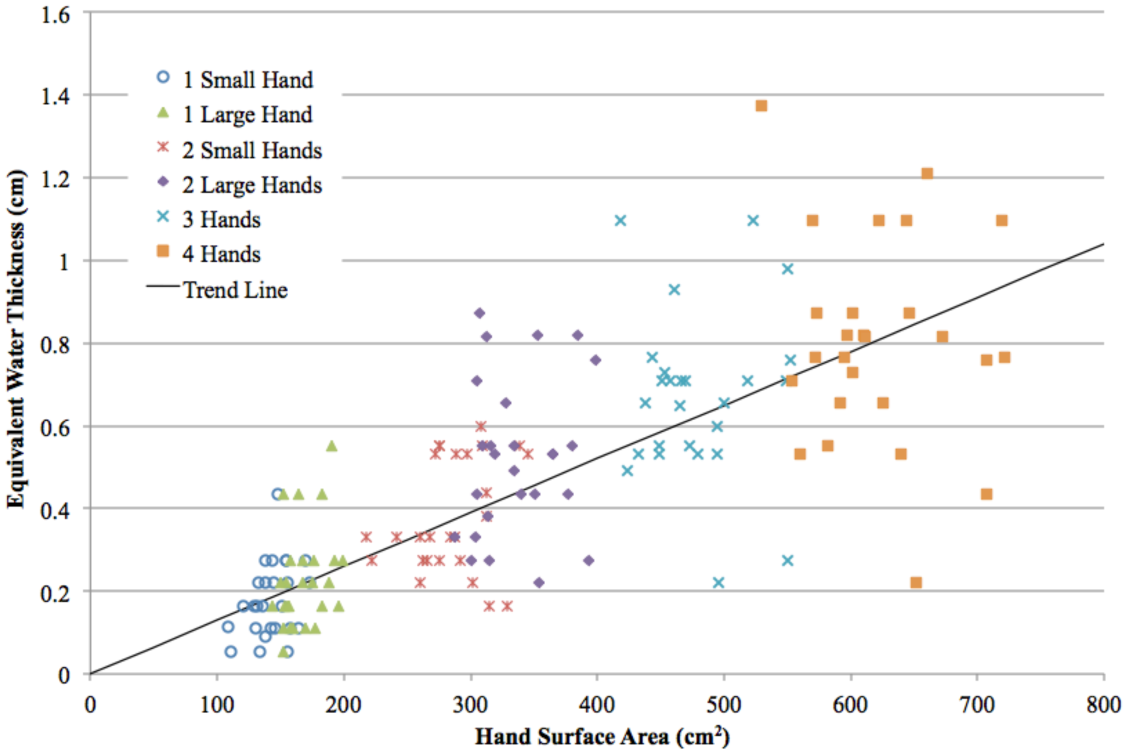

Figure 7: Equivalent Water Thickness as a Function of Hand Surface Area

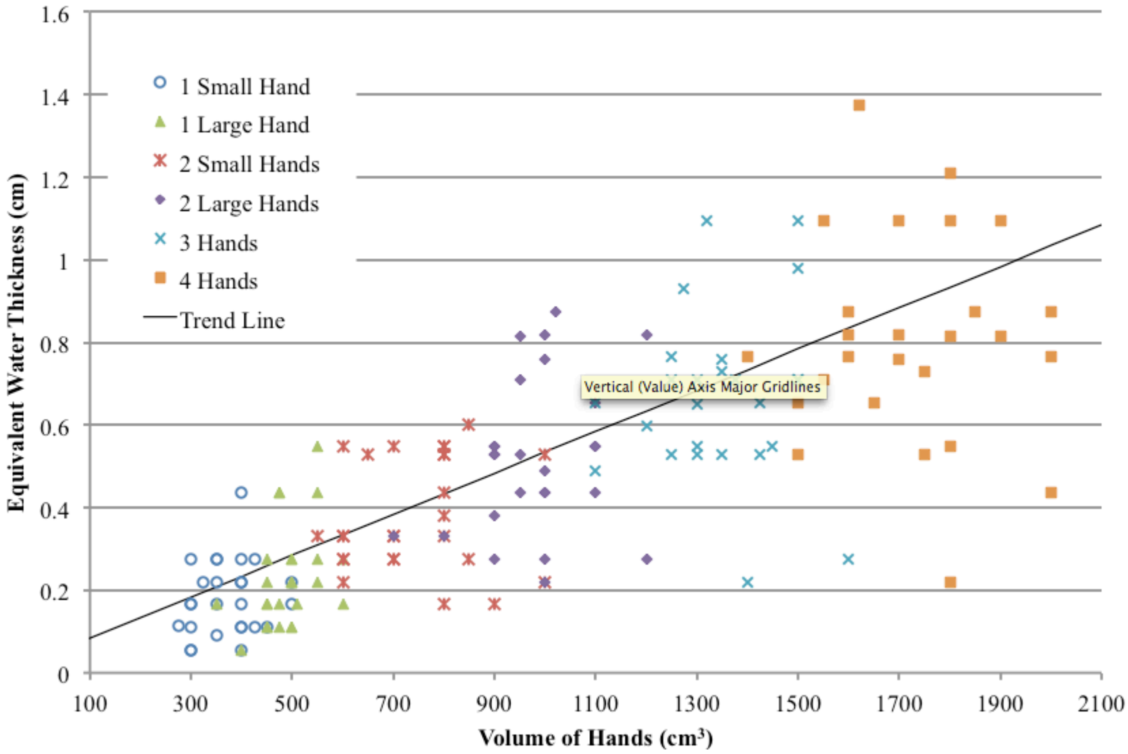

Figure 8: Equivalent Water Thickness as a Function of Hand Surface Area

As shown in Figures 7 and 8, equivalent water thickness appeared to vary linearly with both hand surface area and hand volume. A difference was clearly seen between small hands (open circles) and large hands (filled triangles). The vertical scatter in the data could be due in part to effects other than hand geometry, such as differences in operator body size, hand/body placement relative to the detector, and overlapping hands. Other anatomical differences in hands, such as thickness, could also contribute to measurement differences. Additionally, the largest variation was seen in the four hand measurements, which could be a result of the aforementioned difficulties in placing the fourth hand on the lower half of the TACS.

In all cases, four hands were shown to be inferior to 2.54 cm of water reflection; as shown by the above graphs, the maximum equivalent water thickness achieved was 1.4 cm (0.55 inch) for four hands. Two hands produced a maximum equivalent water thickness of 0.9 cm.

4 CONCLUSIONS

This study presents an experimental basis for equating operator hand reflector worth to an equivalent water thickness. The experimental assembly, due to its compact size (low surface area) and hard neutron leakage spectrum, ensured a near optimal reflector worth for each operator hand. Results from this study indicate that the one inch (2.54 cm) of water criterion for bounding operator hands is highly conservative. Thus, relaxation of the 2.54 cm criterion to account for reflection by operator hands could be argued in many cases. For example, if an operation has only one person handling material at a time, half an inch of water reflection would easily bound the likely potential reflection from the operator’s hands.

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6 REFERENCES

1. C. Percher, D. Heinrichs, S. Huang, and R. Hudson, "Hands-on Nuclear Criticality Safety Training at Lawrence Livermore National Laboratory," *Transactions of the American Nuclear Society*, (November 2010).
2. R. Buck and E. Lent, *COG: A Multiparticle Neutron Transport Code, Version 10*, Lawrence Livermore National Laboratory, (released February 2006).